Resource Allocation Scheme Design in Power Wireless Heterogeneous Networks Considering Load Balance

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Abstract. Recently, in heterogeneous smart grids, mobile network traffic and various power interconnection services grow in a high way. Caching the service at the edge of smart grid network is a common optimization method to reduce the heavy network traffic. In this paper, we propose a cooperative resource allocation scheme in heterogeneous smart grid networks. Firstly, the effect of computing and channel resources on the initial latency of the electric services is studied. Secondly, the model of topology and resource distribution in the network is established, with the goal of minimizing the overall network delay. Thirdly, an algorithm combining KM matching and genetic algorithm is proposed to solve the proposed problem. Finally, the simulation results show that the proposed algorithm optimizes the average delay of the smart grid service.

Keywords: Heterogeneours smart grid networks · Overlapped clustering · Resource allocation

1 Introduction

Smart Grid (SG) is a new generation of power generation, transmission and distribution systems that have emerged in recent years. Its purpose is to manage power resources more effectively [1]. In recent years, with the development of mobile network, 5G technology is maturing day by day. 5G technology can match the emerging services of smart grid due to its advantages of large bandwidth, low delay, high reliability and communication capability of massive connections [2]. However, the following is the problem of excessive mobile network traffic. At the same time, for the operation of smart grid business, a reliable, safe and efficient communication is needed [3].

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Uplink service content occupies a major part of mobile network traffic. How to deal with uplink content transmission is one of the key issues to alleviate the high load of smart grid. At present, the combination of edge cache and smart grid is an effective solution [4]. By caching the content of the core network at the edge of the mobile network, users can preferentially obtain the required content at the base station closer to the user equipment. The backhaul link load from the core network to the edge base station is greatly reduced.

With the development of mobile edge computing, base stations in mobile networks have certain computing capabilities. These computing resources can play a role in content caching. In mobile video services, high-quality versions of the same video can be converted to low-quality versions through transcoding. In this way, users' requests for different versions of the same video can be met by combining higher version videos with video transcoding. This idea is reflected in edge caching: when caching a popular content, we do not need to cache all its versions, but only cache the higher-quality versions, thereby increasing the probability of cached content being used, and then greatly the utilization of cache space. Some studies have optimized the overall network delay or transmission rate. Reference [5] gives different locations where content coding occurs and different delivery methods resulting from it, calculates the network delay for the content transmission, and gives an online cache update strategy based on this. Reference [6] used the Starkelberg game algorithm and many-to-many matching algorithm to allocate the buffer and radio resources in the network to achieve higher transmission rates. Reference [7] proposed a cooperative caching strategy, which caches only the initial part of a part of video content, which has reached a higher cache utilization rate, thereby reducing the average network latency. Another part of the research is dedicated to improving the quality of video provided by the network. Reference [8] started with the overall video quality delivered by the network, and studied strategies to maximize video quality under specific channel conditions. The reference [9] paid attention to the QoE performance of the network, and optimized the average video quality provided by the network through a retention-based collaborative caching strategy. In addition, some researchers have optimized energy consumption. Reference [10] gives the energy consumption of video caching, transcoding, and delivery, and it is optimized as a whole using annealing algorithms.

Due to the large number of power equipment, it can be regarded as an ultra-dense scene. With the development of UDN networks, the transmission mode of a user equipment connected to a base station has changed. The grouping method of overlapping packets is applied in a mobile network to improve the signal-to-noise ratio and anti-interference ability of communication between a base station and a user. Reference [11] proposed a user-centric overlapping grouping method, and designed a spectrum allocation scheme based on the graph theory framework, which improved the overall transmission efficiency. Reference [12] proposed a dynamic clustering scheme based on overlapping clusters, which improved the output signal-to-noise ratio. In the cache placement and distribution process, the

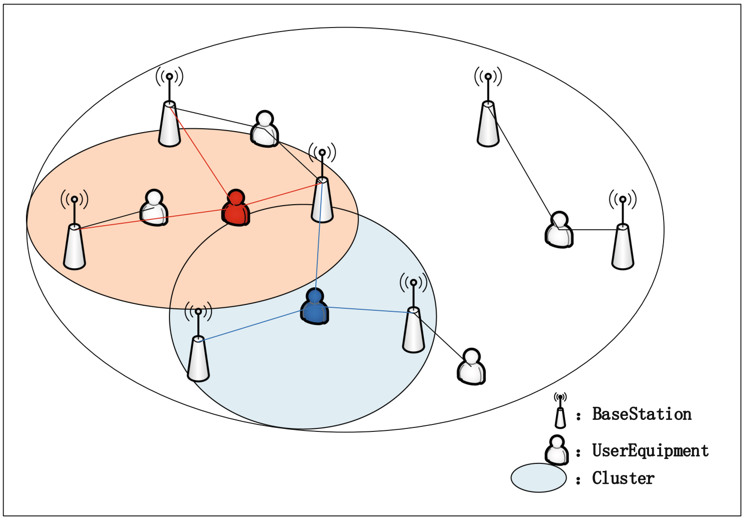

Fig. 1. System model of overlapped clustering in smart grid network

idea of overlapping packets also helps improve the allocation efficiency of cache, computing, and communication resources.

With the development of electric services, the delay of service requirements has gradually increased, and it is difficult for a single node to independently process user video requests. At the same time, because the node density in UDN is relatively large, the idle resource utilization of nodes can effectively improve network performance. In this scenario, this paper proposes a cooperative transcoding and distribution mechanism based on overlapped clustering. First, the strategy of overlapped clustering in ultra-dense networks is considered. Secondly, a mathematical model of node clustering and heterogeneous resource distribution is established. The optimization of the initial buffering time of the video is used to divide the overall network delay optimization problem into two sub-problems: clustering and resource allocation. Thirdly, a resource allocation algorithm combining KM matching and genetic algorithm is proposed. Based on the optimized KM matching algorithm, the nodes in the ultra-dense network are overlapped clustered, and the genetic algorithm is used to allocate the grouped computing and channel resources. Finally, it can be seen through simulation that the proposed algorithm can effectively reduce the average initial buffer delay of the user.

The rest of this article is structured as follows. The second section gives system modeling and problem simulation. The third section gives the KM and genetic algorithm methods. Section 4 lists the simulation results and corresponding analysis. Finally, Sect. 5 summarizes the full article.

2 System Model

In this section, we introduce the system model and formulate grouping and resource allocation issues.

2.1 System Model

This paper considers that in a smart grid network, as shown in Fig. 1, J small base stations are divided into a maximum of I cluster by overlapping clustering to provide services for I users. Due to the large number of power equipment, it can be regarded as an ultra-dense scene based smart grid network. For simplicity, this article represents the set of user equipment as $I = \{1, 2, ..., I\}$ and the set of base stations as $J = \{1, 2, ..., J\}$. Among them, i, j represent the i-th user and the j-th base station, respectively. The connection relationship between each user and the base station is represented by a matrix $X = [x_{ij}]$. When $x_{ij} = 1$, it means that base station j provides service for user i. Conversely, $x_{ij} = 0$ means that the current base station j does not provide service to user i. It is assumed that in the current area, each base station occupies a different frequency band range, and different users are allocated different subcarriers for communication, so the interference between different base stations and users is not considered. A cache and MEC server are deployed at the base station to provide cache and computing resources. The amount of computing resources at the base station is represented by the number of video bits per second that the CPU can transcode, and is denoted as C_j^f. Assuming that the transmission power of each base station in the network is the same, the communication resources of different base stations are mainly compared by bandwidth, and the total subcarrier bandwidth allocated by each base station is represented by W_{ij}. The video content on the network has multiple definition versions. This article describes versions of videos by the bit rate of the video contents, which is represented by the symbol R. The version of the video content requested by user i is represented by the bit rate R_i^s; and the version of the video content cached at the base station is represented by the bit rate R_j^c. Between different versions of the same video, lower-bit-rate video content can be transcoded from higher-bit-rate video content.

In this article, it is assumed that the users always has enough buffer space to support the transmitted video stream to be buffered in the user equipment. After the user sends a request for video content to the base station, each node in the base station group sends video content to the user in the form of a video stream at the same time and stores it in the buffer of the user equipment. During this period, it is assumed that the location of the user remains unchanged, the amount of resources provided by the base station does not change, and the wireless channel status does not change. Therefore, it can be considered that the buffering speed of the video content is constant. On this basis, if the user equipment determines that the video content can be transmitted before the end of playback at the current rate, then the video content can start playing. The time from when a user sends a request to when the video starts playing can be expressed by the user's waiting delay τ_{ij}.

2.2 Problem Formulation

In a smart grid network, when a user is served by only one base station j, for each user i, the delay τ_{ij} from its request for a specialized content to the start of playing the video is mainly composed of the calculated delay and the communication delay, namely:

$$\tau_{ij} = \tau_{ij}^c + \tau_{ij}^t \tag{1}$$

When the base station serve content by way of overlapping clustering, the base station needs to determine the content distribution mode according to its own cache. Different distribution methods can be represented by x_{ij}, R_i^s and R_j^c. When the cached video content at the base station does not match the user's request, or the quality of the cached video content is lower than the user's request, the base station cannot provide services, so $x_{ij} = 0$. When the video content cached at the base station matches, but the video quality is higher than the user's request, that is, $R_i^s < R_j^c$, two processes of video transcoding and distribution are required. When the video content and the quality version cached at the base station are consistent with the user request, only the video distribution process is performed, that is, $R_i^s = R_j^c$. The following will model the calculation delay and communication delay of the base station and describe the optimization problem:

1. Calculation Delay

The time required for video transcoding at the base station is related to the total amount of computing tasks and the allocated computing resources. The total amount of calculation tasks can be expressed as the product of the difference between the video bit rate before and after transcoding and the video length. The calculation resource is expressed as the number of bits processed by the CPU per second c_j^f. Assume that the user $i \in \mathbb{I}$ requests different versions of the same file. The minimum bit rate requirement for each version is R_i^s. The bit rate of the video version buffered in base station j is R_j^c, and t_v is the total video duration. Therefore, the calculated delay is:

$$\tau_{ij}^c = \frac{t_v \cdot (R_j^c - R_i^s)}{c_{ij}^f} \tag{2}$$

2. Communication Delay

The communication delay includes two parts which are the uplink upload and downlink transmission, respectively. Assume that the user has sufficient storage space for video caching. In order to avoid interruption during video playback, it is necessary to pre-cache video content of size $\tau_{ij}^t \cdot R_{ij}^r$, τ_{ij}^t is the communication delay when the user requests it, that is:

$$t_v \cdot R_i^s = (t_v + \tau_{ij}^t) \cdot R_{ij}^r \tag{3}$$

$$\tau_{ij}^t = (\frac{R_i^s}{R_{ij}^r} - 1) \cdot t_v \tag{4}$$

Among them, the frequencies between base stations are different, and each base station allocates its own channel bandwidth to different users according to frequency bands. Therefore, without considering path loss and mutual interference between users, there are:

$$R_{ij}^{r} = W_{ij} \cdot \log\left(1 + SNR_{ij}\right) \tag{5}$$

$$SNR_{ij} = \frac{P_j^s \cdot |h_{ij}|^2}{\sigma^2} \tag{6}$$

Where W_{ij} is the sub-channel bandwidth allocated by the base station to users, and P_j^s is the maximum transmit power of the base station.

3. Problem Description

In the network, the base stations cooperate in a manner of overlapping clusters. The connection relationship between each user and the base station is represented by a matrix $X = [x_{ij}]$. For the waiting delay of user i τ_i:

$$\sum_{j=1}^{J} x_{ij}(\tau_i - \tau_{ij}^c) \cdot R_{ij}^r = t_v \cdot R_i^s \tag{7}$$

$$\tau_i = \frac{\sum_{j=1}^{J}\left(x_{ij} \cdot R_{ij}^r \cdot \tau_{ij}^c\right) + R_i^s \cdot t_v}{\sum_{j=1}^{J} x_{ij} \cdot R_{ij}^r} \tag{8}$$

Then the minimum average waiting delay of users in the network is:

$$\begin{aligned} \min \tau = min \frac{1}{I} \sum_{i=1}^{I} \tau_i \\ \texttt{s.t.}\quad C1: x_{ij}\left(R_j^c - R_i^s\right) \geq 0 \\ C2: \sum_{i=1}^{I} x_{ij} \leq S_j \\ C3: \sum_{i=1}^{I} x_{ij} W_{ij} \leq B_j \\ C4: \sum_{i=1}^{I} x_{ij} c_{ij}^f \leq C_j^f \end{aligned} \tag{9}$$

Constraint 1 indicates that the quality of the version of the video cached at the base station should be higher than the quality of the video requested by the user in the overlapping clusters, so that the high-level video can be converted to the low-level through video transcoding. Constraint 2 indicates that the number of users connected to each base station should not exceed the maximum number of access users. Constraints 3 and 4 respectively indicate that the bandwidth allocated by the base station and the computing resources should not exceed the total amount of resources at the base station.

3 Overlapping Clustering and Resource Allocation Algorithm

3.1 Algorithm Design

In this paper, the optimization problem is decomposed into two sub-problems, one is the overlapping clustering problem of the base station, and the other is the problem of base station communication and computing resource allocation. In the overlapping clustering problem, the improved KM algorithm is used to match the user and the base station to find the anchor node of the overlapping cluster. The version of the file requested by the user is cached at the anchor node. Through the anchor node, users can get basic quality of service guarantee. In the resource allocation problem, this paper uses the genetic algorithm to allocate the channel resources and computing resources of the base station.

In the grouping problem, the network topology of the base station and the user can be regarded as a bipartite graph. The bipartite graph can be defined as $G = (V_1, V_2, E)$, where V_1, V_2 is two non-empty subsets, and $V_1 \cap V_2 = \varnothing$. E is the set of edges between V_1, V_2. Since each edge has different weights E, and can be expressed as $E = \{w_{ij}\}$, where $i \in V_1, j \in V_2$ and w_{ij} are weight vectors between vertex i and j. In the scenario of the ultra-dense network considered in this paper, the number of users is not more than the number of base stations, and there is no intersection between the two sets. Therefore, let I, J be V_1, V_2. Consider the delay of one-to-one service between the base station and the user, and use the inverse number of the delay as the weight w_{ij} of the bipartite graph side. Therefore, as long as an optimal match of this bipartite graph is found, the anchor node allocation method with the most benefit (the lowest instantaneous delay) can be obtained. After the assignment of the anchor node and the determination of the caching version of the base station are completed, the grouping result of overlapping clustering can be preliminarily determined according to the caching situation of the small base stations around the user.

The KM algorithm is a typical algorithm for solving the optimal matching problem with weighted bipartite graphs. The top matching is used to convert the optimal matching into the maximum matching problem. In general, when $|V_1| = |V_2|$, the KM algorithm can be used to find the optimal solution. In this article, due to $|J| \gg |I|$, the traditional KM algorithm needs to be improved to adapt it to the needs of specific scenarios. Specifically, since the grouping method in this paper is overlapping clustering, in order to ensure the basic quality of service of users, at least one node needs to be allocated for users. After forming a group, a node is also needed in the group to collect and distribute user information. This node is called an anchor node. In the overlapping clustering problem, a key problem is to find a one-to-one match in the network topology, so that each user owns an anchor node independently. In particular, in the time-delay optimization problem in this paper, it is necessary to ensure that the user's time-delay is the smallest in the subgraph formed after the one-to-one matching. Since the KM algorithm is essentially a process of continuously relaxing restrictions and finding the best match through the Hungarian algorithm, when the number of base station nodes is significantly greater than the number of user nodes, the KM algorithm can also be used to solve. Different from the traditional method, the KM algorithm in this paper will stop when the user equipment finds a matching base station, and the remaining base stations are used as auxiliary nodes when overlapping clusters are assigned to each group for cooperation.

In this paper, the user set first needs to assign initial values to the nodes in the user set I and the base station set J. Here, the top index of the base station set is set to zero, and the top index of the user set is assigned to the largest weight among all connections. Construct a subgraph of a bipartite graph. The subgraph contains all the nodes of the bipartite graph, and the edges satisfy the arbitrary side length weight equal to the sum of the two superscripts. Then look for the augmentation road from i_0 in the subgraph. The set of nodes in $\mathbb{I}$ on the augmented road is added to the set $\mathbb{S}$, and the set of nodes in $\mathbb{J}$ is added to the set $\mathbb{T}$. When the augmentation path is not found and the number of nodes in the set $\mathbb{S}$ is smaller than the number of nodes in the set $\mathbb{I}$, the node top label needs to be adjusted so that the sub-picture contains more edges. That is, the set $\mathbb{S}$ is reduced at the same time, and the top flag of the set $\mathbb{T}$ is increased until all the nodes in the set $\mathbb{I}$ are included in one augmented road, that is, an optimal match is obtained. After finding the optimal match and determining the anchor node, the base station caches the video according to the video version request of the user, and the base station without the user randomly selects the video version for caching. Thereafter, each user determines its own base station grouping according to the reachability and buffering conditions of the surrounding base stations. This results in overlapping clustering results for the network.

After solving the grouping method, in the resource allocation problem, this paper finds a sub-optimal solution through genetic algorithm. Genetic algorithm is an optimization algorithm based on the principle of genetic selection. It is similar to the principle of chromosome generation in biology. It takes all individuals in the group as the object, and under the guidance of randomization technology, efficiently searches a coded parameter space. As the number of iterations increases, the fitness of the individuals in the group gradually increases, and finally converges to a suboptimal solution. Among them, selection, crossover and mutation constitute the genetic operation of the genetic algorithm. The specific operation process includes:

1. Initialization

In the genetic algorithm, the chromosome should contain information about the solution to the optimization problem. Therefore, the possibility of all solutions needs to be presented in the chromosome. Different coding methods can be used to map the solution of the problem to the chromosome through genes, so that each possibility may correspond to a chromosome. In the genetic algorithm, the coding problem is the key of the genetic algorithm. Both the mutation operator and the crossover operator are affected by the coding method. Therefore, the coding problem greatly affects the efficiency of the genetic calculation. Common coding methods are: binary coding, Gray code, floating point coding, multi-parameter cascade coding, multi-parameter cross coding, etc. Among them, the binary coding method uses a binary symbol set $\{0, 1\}$ for coding, and its individual genotype is a binary coding symbol string. Although this coding method is simple to operate, it is not suitable for continuous function optimization. Gray code improves the local search ability of the algorithm on the basis of binary coding, but the accuracy is still greatly restricted. In floating-point encoding, individual gene values are represented by a real number within a certain range. Its high precision is suitable for continuous variable problems.

2. Fitness function

In genetic algorithms, fitness is an important basis for selecting individuals, and it is also an important indicator that reflects the optimization effect of individual corresponding solutions. Therefore, the optimization goal is usually converted into individual fitness according to certain rules. In this paper, the reciprocal of the optimization goal is selected as the fitness.

3. Choose

The selection operation is a process of selecting different individuals according to the performance of the individuals in the parent group to inherit to the next generation. Commonly used selection operators include roulette selection, random competition selection, best retention selection, etc. This article adopts the method of combining the best reserved choice and the roulette choice, to keep multiple copies of the best individual completely, and the remaining individuals are selected through the roulette choice.

4. Crossover

Crossover operation means that two chromosomes produce new individuals by exchanging some genes. Crossover operators include single-point crossover, multi-point crossover, uniform crossover, and arithmetic crossover. Since the method chosen in this paper is the encoding of floating-point numbers, the arithmetic crossover is selected, and a new individual is created by the linear combination of two individuals.

5. Variation

Variation refers to the process in which certain genes in an individual's chromosome are replaced with other alleles. Common mutation operators include basic bit mutation, uniform mutation, boundary mutation, non-uniform mutation and Gaussian approximate mutation. In this paper, the uniform mutation method is used to replace the original gene value with a random number that is evenly distributed within a reasonable range to generate new individuals.

Since genetic algorithm has good global convergence performance of discrete variables under relatively low complexity, it is suitable for solving the resource allocation problem proposed in this paper. In this paper, the communication and computing resources of the network are respectively expressed by two $I \times J$ matrices. The matrix stores the proportion of the resources allocated by the user to the total resources of the base station, and the proportions of frequency band resources and computing resources are w_{ij} and c_{ij} respectively. Since w_{ij} and c_{ij} can be any value within $(0, 1)$ in the algorithm of this paper, the two matrices are merged into a chromosome by means of floating-point encoding. After the chromosome construction is completed, the optimal resource allocation matrix is obtained through chromosome crossing, mutation, and inheritance.

3.2 Algorithm Flow

The algorithm proposed in this paper mainly includes two parts, KM algorithm for base station grouping, and genetic algorithm for resource allocation. The execution process of the algorithm is shown in the following table.

Algorithm 1. Resource Allocation Algorithm Based on KM Matching Algorithm and Genetic Algorithm

Input: I, J, B_j, C_j, S_j
Output: Grouping and resource allocation results

Initialization:
The distance matrix D between the user and the base station, the chromosome S, the top standard value of the base station q_j=0, the matching node $I', J'=\varnothing$
repeat
    while $i \in I$ **do**
        Use the minimum value of the corresponding column in D as the superscript value p_i
        if $p_i+q_j \leq d_{ij}$ **then**
            $I'=I'+i$, $J'=J'+j$
        else
            Record the difference $g = p_i+q_j - d_{ij}$
        end if
    end while
    if $i \in I'$ **then**
        p_i=p_i-$g_{\min}$
    end if
    if $j \in J'$ **then**
        q_j=q_j+$g_{\min}$
    end if
until $I'=I$
repeat
    while $s \in S$ **do**
        Find the corresponding fitness
    end while
    Selection, crossover, mutation
until Algorithm termination

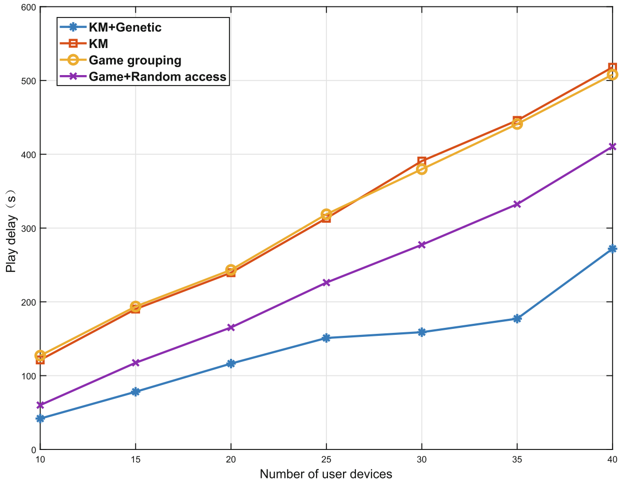

Fig. 2. Relationship between the overall network delay and the number of users

4 Simulation Results and Discussions

In this paper, a mobile network is composed of 60 micro base stations and 10–40 user equipments randomly generated in a 200 m area. The frequency band resources of the base station are divided into multiple sub-channels according to frequency for serving different users. Transcode and distribute the same video on the network. The video is divided into three versions of 32M, 40M and 48M with different bit rates, and the duration is unified to 60 min. Assuming that each user has different video version requirements, the base station chooses to cache the appropriate version according to the grouping situation. Finally, the average waiting time of users in the network is counted to reflect the network performance.

In order to verify the performance of the proposed algorithm, this paper selects four packet transmission methods for comparison, including KM algorithm, game algorithm and other one-to-one grouping algorithms, game and random allocation combined many-to-one grouping algorithm, KM and genetic many-to-many overlapping clustering algorithm. The traditional KM algorithm can find a service node for the user, and from the perspective of the entire network, the average distance of the user is the shortest. By examining the distance between the user and the base station, the game algorithm preferentially selects the user with the closer distance to match with the idle base station, and finally forms a one-to-one allocation of the base station. The combination of game and random access can form a one-to-one allocation, based on the principle of proximity to allow idle base stations to serve the closest users, and then form a base station group, but each small base station can only exist in Within a group. This method and the overlapping clustering algorithm proposed in this paper use genetic algorithm to allocate resources within the group.

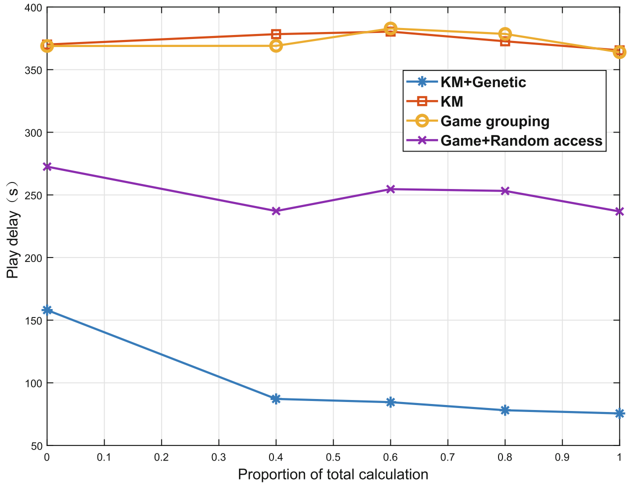

Fig. 3. Relationship between the overall network delay and the base station band resources

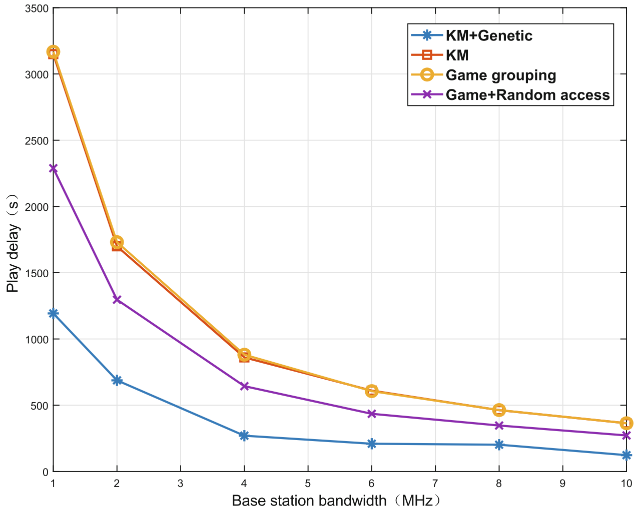

Fig. 4. Relationship between the overall network delay and the base station computing resources

In order to consider the relationship between the number of users and network performance, this article changes the value of the number of users and compares the delay performance under the four comparison algorithms. As shown in Fig. 2, when the number of users increases, the delay of each algorithm increases. Among them, the one-to-one grouping algorithm has poor performance due to certain resource idleness. The combination of game and random access has better performance, but when the number of users increases, the speed of performance reduction is still greater. The overlapping clustering algorithm proposed in this paper can optimize the overall performance according to the actual situation, and the adjustment space for resource allocation is larger, so the performance is better and the impact of the increase of users is relatively small.

Considering the impact of communication and computing resources on the performance of the algorithm, as can be seen from Fig. 3, with the increase of frequency band resources, the delay of the algorithm generally decreases, and the delay performance of the network increases first and then tends to be stable. Specifically, the latency of the two one-to-one grouping algorithms is still relatively high. When the network's frequency band resources are insufficient, the performance declines quickly, making it difficult to guarantee the quality of service that users get. The many-to-many overlapping clustering algorithm proposed in this paper has the least impact on the total delay when the frequency band resources are small, so it shows certain advantages.

In terms of computing performance, as shown in Fig. 4, the one-to-one grouping algorithm has relatively fixed resources, so it fluctuates less with changes in computing resources. With the reduction of computing resources, the amount of resources that can be used for transcoding in the two multi-pair packet algorithms is reduced, which has a greater impact on the final delay performance. However, the resource allocation algorithm proposed in this paper still has certain performance advantages.

5 Conclusion

This paper proposes a resource allocation algorithm based on overlapping clustering for transcoding and distribution of multi-version video. This article considers the optimization problem in two phases. Firstly, the KM matching algorithm is used to select the anchor node corresponding to the user, and the overlapping cluster is completed. The second stage uses the genetic algorithm to allocate resources within the group to achieve global optimization. The simulation results show that the algorithm has good delay performance in the video transcoding distribution of small base stations, especially in the scenario with less resources.

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